MOVEMENT OF AN UPPER-AIR LOW OVER THE WESTERN UNITED STATES, OCTOBER 16–24, 1957

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1. INTRODUCTION

Early on the morning of October 16, 1957, a rather ordinary-looking trough aloft moving eastward arrived over the Pacific Coast in the vicinity of Vancouver Island, B. C. There it began to form a closed circulation at most of the intermediate levels. On the surface there was no associated Low nor frontal system and only a little weather.

This was the beginning of a cold Low aloft whose irregular movement in the succeeding seven days was to cause a series of consistently poor upper-air prognostic charts over the western United States by both the National Weather Analysis Center and the Joint Numerical Weather Prediction Unit.

It is the intent of this study to show what happened and insofar as possible to explain why—to show how the Low was actually forecast and evaluate some of the better known techniques that were or could have been used in its prediction.

2. MOVEMENT AND RELATED WEATHER

Figure 1 shows a sequence of 500-mb. charts at 24-hour intervals which span the period under study. It will be noted from this series that the Low reached its maximum intensity near mid-period when it was over central and southern California. At approximately the same time sea level pressures under the Low reached minimum values which permitted the only occasion in the sequence for a clear-cut analysis of a closed Low at the surface. The degree of deepening at sea level was about the same as that occurring at 500 mb., indicating that most of the deepening was due to warming at levels above. This was borne out by the observation of very little change in the mean virtual temperature field between 1,000 and 500 mb.

Tracks of the low center (fig. 2) at 500 and 200 mb., and of the cold core in the 1,000-500-mb. thickness, show very good similarity in both direction and speed. At 700 mb. the path was essentially that at 500 mb., but at 850 mb. the analysis of a closed center was too often questionable or impossible to allow tracking.

It will readily be appreciated that such erratic motion presented difficulties in predicting the track. Note in particular the abrupt change in direction and immediate acceleration at 0000 GMT on the 19th, the rapid deceleration at 0000 GMT on the 21st, and the nearly phenomenal acceleration again 24 hours later.

Surface weather associated with the vortex was neither severe nor record-breaking. The Low was, however, responsible for temperatures 3° to 6° F. below normal over a large portion of the West and for above normal rainfall in some sections, particularly western Nevada [1], a normally arid region. The relatively heavy precipitation in Nevada occurred at mid-period of the series while the Low was at its maximum intensity.

Perhaps more important than the surface weather in this situation were the winds aloft. Forecasts of winds aloft certainly must have been notably poor for periods in excess of 12 hours and at certain critical times and localities.

3. CONTRIBUTING CAUSES AND EFFECTS

In attempting to explain what caused the Low to move as it did one must, as in most similar meteorological matters, view the problem completely by hindsight.

One of the first factors to be considered is that of the tendency field. Dashed lines in figure 1 show the height change in 200-ft. intervals at the 500-mb. level for the 12-hour period immediately preceding the individual chart. It will be noted in figure 1A that the centers of rising and falling heights were very nearly in a west-east line, with rises to the west and falls to the east indicating eastward motion. In figure 1B the orientation has become northwest-southeast with the tendency component contributing to motion toward the southeast. In figure 1C, although not readily evident, the rise area previously lying to the northwest has split, leaving one cell northwest of the center while the other has moved to the northeastern sector. This was quickly ascertained from the 1200 GMT analysis which revealed the rise center at a position directly north of the fall center with protuberances toward the southeast and southwest. It will also be noted in figure 1C that the fall area has diminished about 200 feet. This stage left two tendency vectors, both of lesser magnitude than before, one directed toward the southeast and the other toward the southwest. In figure 1D the fall area east of the center has disappeared and a new region of fall has appeared to the west-southwest giving vectors directed toward the west-southwest and the south. Refer-

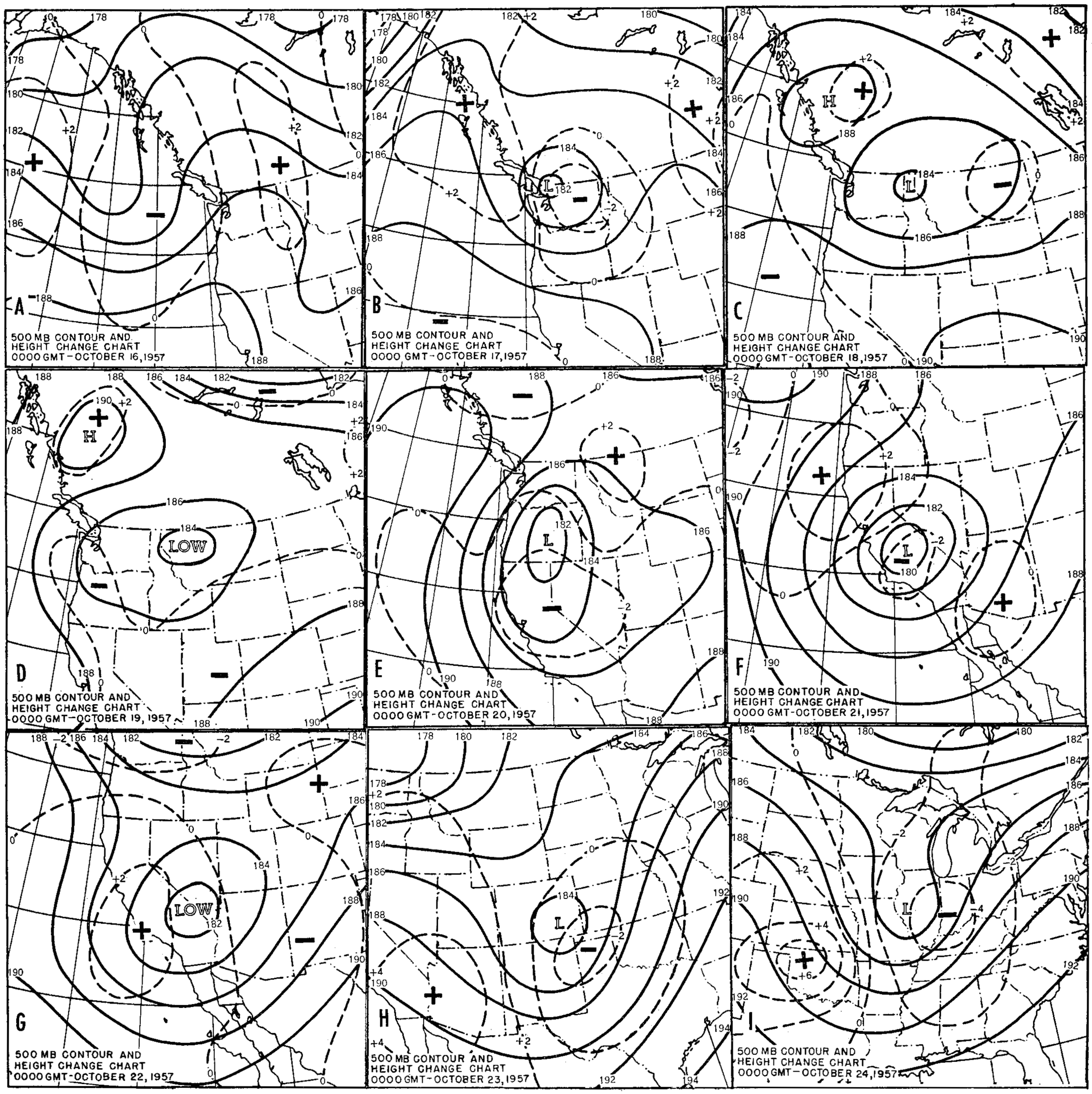


FIGURE 1.—Series of 500-mb. charts and 12-hour 500-mb. height changes (dashed lines, hundreds of ft.) showing location and configuration of Low and change areas at 0000 GMT, October 16–24, 1957.

ence again to the track chart (fig. 2) shows that the Low reached its easternmost extremity at this point before turning back. In the remaining charts of figure 1, it can be seen that the tendency vector indicated very well the instantaneous direction of movement. Of further interest is the intensification of the change fields toward the end of the series while the Low was actually weakening. This could be correlated with only a much more rapid movement of the system.

Still another element to be considered in explanation of the path taken by the Low is the overall steering effect of the current in which the Low was embedded. This, of course, entails study of the current in various quasi-horizontal planes which must in the end be combined to include also those forces acting vertically.

First let us examine the effects of the jet stream and of the jet maximum in that stream. In figure 3 a more or less combined or averaged position and speed of the jet

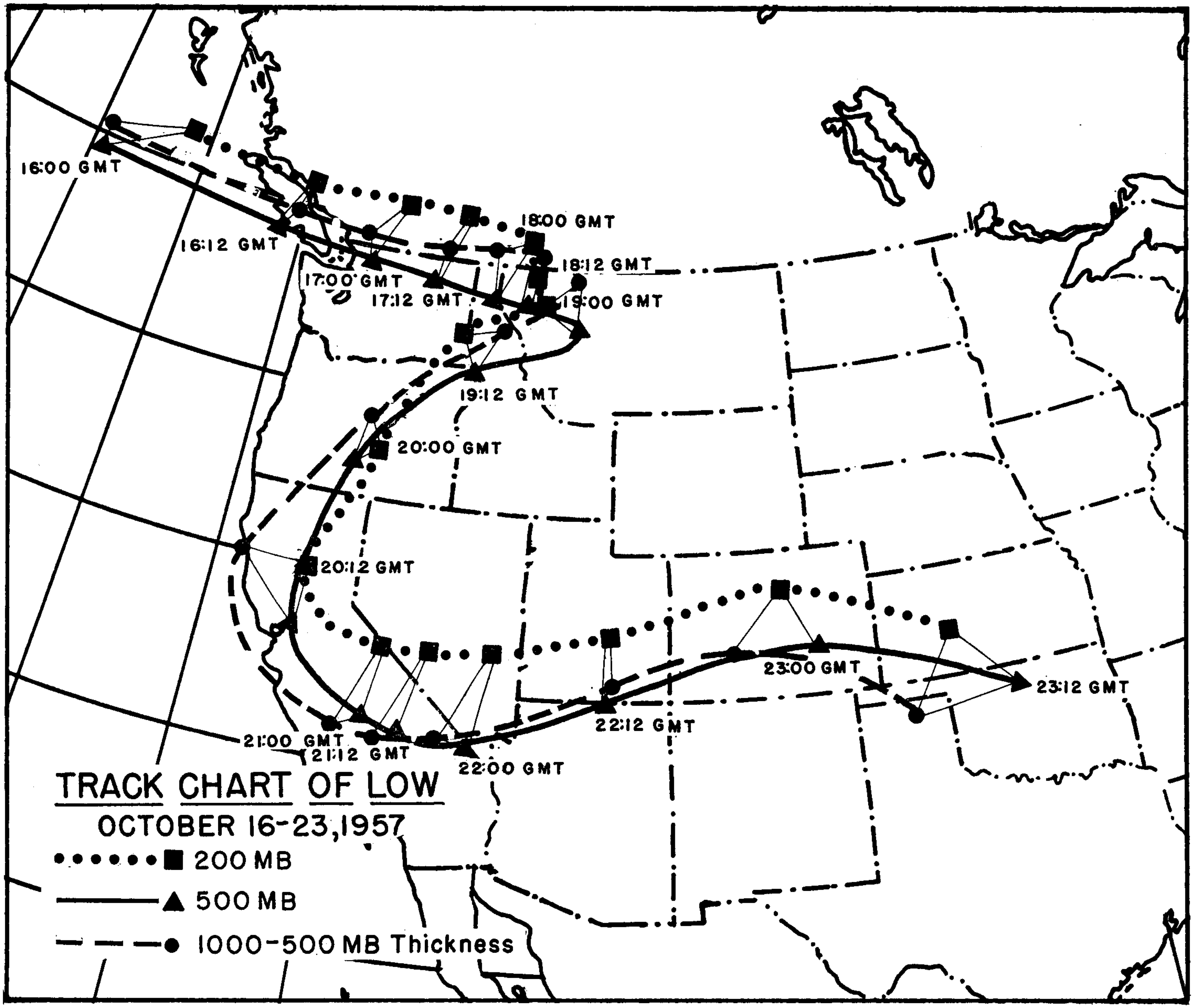


Figure 2.—Track of Low at 500 mb. and 200 mb. and of 1000-500-mb. thickness cold core, 1200 GMT, October 16 to 1200 GMT, October 23, 1957.

maximum for several different pressure surfaces (primarily 300, 250, and 200 mb.) are presented in relation to the center of the Low with respect to time. This shows that the strongest flow was about 70 knots in the southwestern quadrant the first day shifting slowly to the southeastern quadrant and dying rather abruptly the third day. During the middle of this period or about the beginning of the second day another maximum began to appear in the northwestern quadrant. Except for a temporary leveling off on the 20th, it gradually intensified and moved around the center to the southeastern quadrant where on the fifth day it reached a peak speed of approximately 150 knots. Figure 4, which gives the direction and speed of movement of the Low, is drawn to the same time scale as figure 3 so as to show the relationship that existed between the motions of the Low and the jet maximum. Of seemingly considerable import is the sharp change in direction of the Low on the 19th when the older maximum dissipated and the new peak to the northwest rapidly built up. Of further interest is the gradual recurvature of the Low as the jet maximum moved around the center. Not satisfactorily explained, however, in figures 3 and 4 is the sudden deceleration of motion on the 21st and rapid acceleration again 12 to 24 hours later. This apparently occurred at a time when the jet speed was increasing at a maximum rate. Perhaps the leveling off of the jet speed on the 20th was related to the deceleration, with a time-lag involved. Still, if this was so, one might rather expect a definite dip in the curve.

Another aspect of the overall steering current, seemingly of more than ordinary importance, was that at certain intervals the surface and lower-level flow pattern was opposed to the general circulation pattern above. This seems to have been most influential around the 18th, 19th, and 20th, just prior to and after the sudden change in direction of movement of the Low. This is shown quite well in figure 5 where the surface flow is northeasterly and increasing under the Low aloft. Actually the circulation at and near sea level had been weak and easterly beneath the Low or trough from the beginning of the series of charts, which seems to explain the slow deceleration toward the east. Late in the series the lower-level flow offers the only obvious explanation for an upper Low movement in a direction south of east.

It may be worthy of some mention also, as indicated by the relative positions of the Low (fig. 2), that nearly all the eastward movement at 500 mb. was in fair agreement with the 200-mb. flow above. It should be noted here that only during the eastward progression was there any appreciable tilt between the two levels. Furthermore, motion of the 200-mb. Low was in good agreement with the 150-mb. flow above it.

Finally to be considered are the components of movement produced by a changing thermal field. For most of this series the Low was termed "cold," which by the usual definition implies little or no advection at levels where it exists. There was, in fact, little advection observable from existing data, and what there was occurred near mid-period and mostly at the higher elevations causing deepening of the center at all levels below. If any appreciable warming or cooling was produced by radiation, vertical motion, or other physical processes, it was not readily discernible. Hence it may be concluded that the thermal factors influencing the Low were for the most part negligible.

All the foregoing discussion has been given in an attempt to point out the various features of the stream of air acting around, above, and below the Low at any particular height to explain why it moved as it did. One may well ask if some of the explanations given may not overlap or even be the cause of others. Certainly the tendency or change field is more in the nature of an effect and probably should be used only to corroborate the net effect of all the causes. At any rate, it has been possible in every case but one to show a flow pattern acting that could cause the Low to move as it did. This one exception is the deceleration around October 21. All explanations attempted here are somehow insufficient.

4. APPLICATION OF PREDICTION METHODS

Next comes the problem of forecasting movement of the Low. Of course the more erratic the path the more difficult the prediction. Nice uniform motions or even regular accelerations and curvature for short periods present no great difficulty. It is the longer-range problem with irregularly moving systems that taxes the meteorologist's capabilities. The low pressure system under study was such a trying case.

For the remainder of this section the discussion will deal with a prognostic period of 36 hours unless otherwise stated.

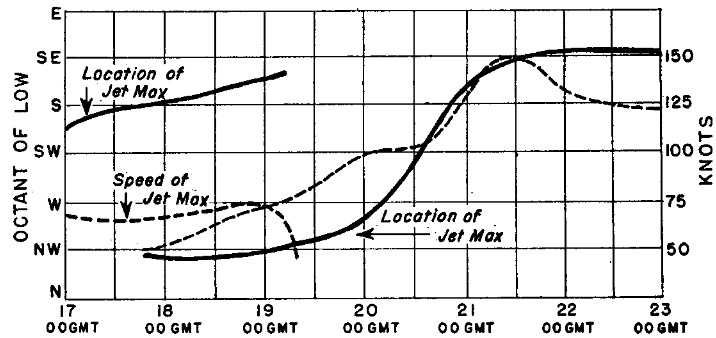


FIGURE 3.—Graph showing location and speed of jet maximum associated with Low, October 17–23, 1957.

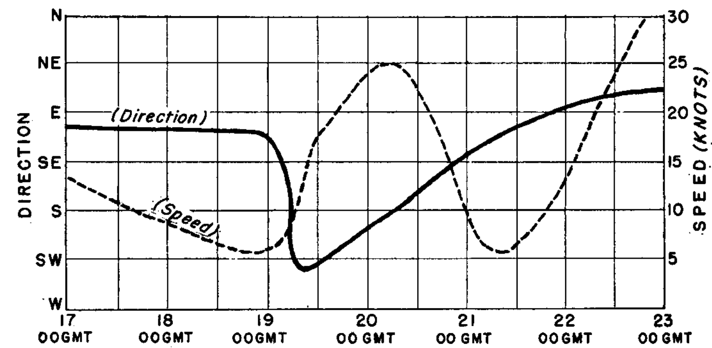


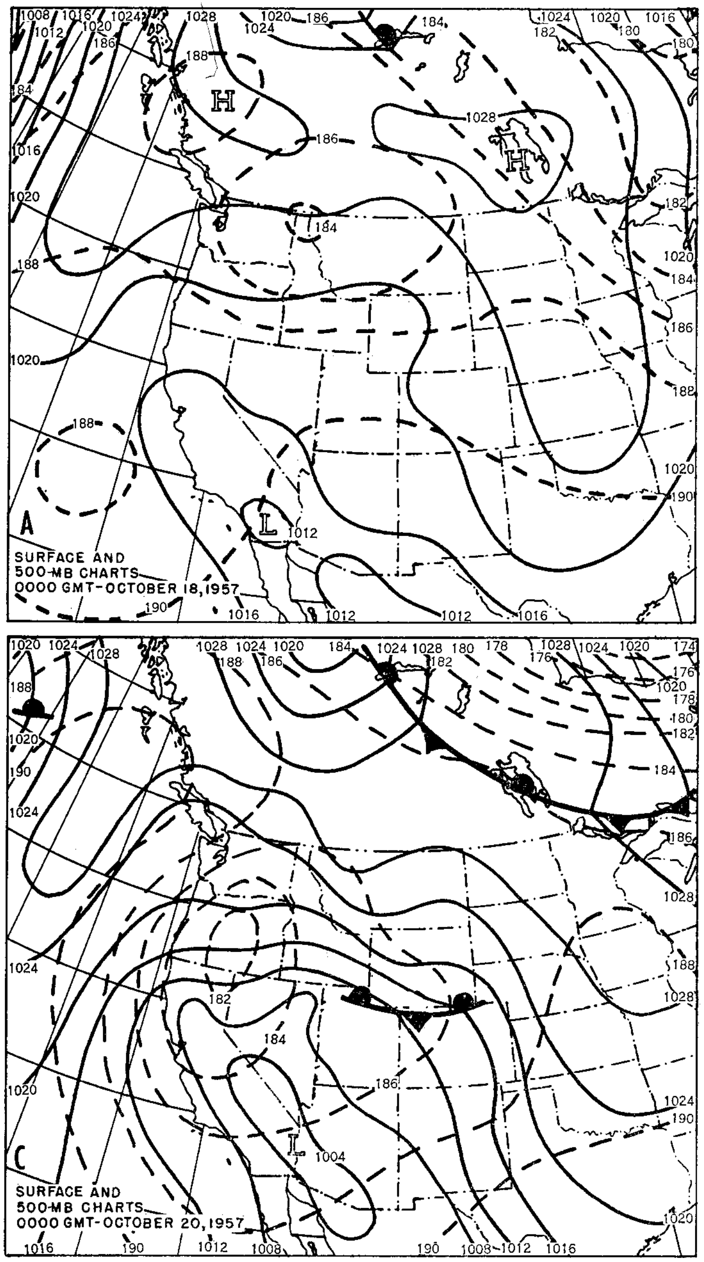
FIGURE 4.—Graph indicating mean speed and direction toward which Low is moving at 500 mb., October 17–23, 1957.

In the two charts of figure 6 is shown a comparison between the observed positions of the Low and the positions forecast by two offices, the National Weather Analysis Center (NAWAC) and the Joint Numerical Weather Prediction Unit (JNWP). As is quickly perceived, neither did well, nor did one prove to be noticeably better than the other in this case. The question arises then whether any of the known objective or subjective techniques would have verified better. Several of these, to the extent time has allowed, have been tested and will be discussed individually as to their value in this particularly difficult case.

First, the process of pure extrapolation proved superior to any other at certain select times but as a whole was very unsatisfactory. Extrapolation could not take account of the numerous reversals of trend shown in the track.

Advection of vorticity in a barotropic field using the Fjørtoft [2] graphical technique was studied briefly. It was abandoned, however, because it was felt the JNWP method incorporates refinements of the same process and would show better the merit of this approach.

As will be seen in figure 6 the JNWP technique moved the Low in a very general path comparable to that of the observed but was consistently too slow, often by a considerable margin. In evaluating this system in the given situation it must be pointed out that because the whole series was largely barotropic in nature methods



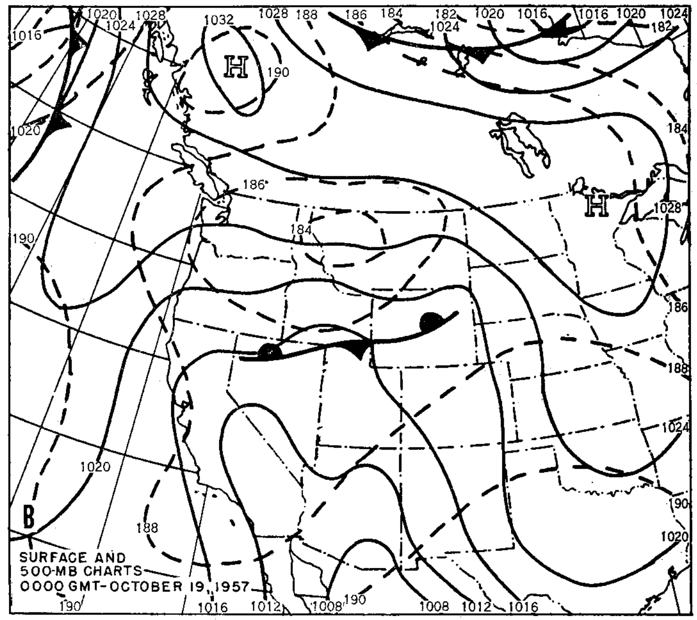


FIGURE 5.—Surface isobars and corresponding 500-mb. contours for 24-hour intervals, October 18–20, 1957, showing relationship of movement aloft to surface flow pattern.

based on barotropic models would have been expected to operate at their near best.

Calculations were made using the Wilson Grid Method [3] for each map of the series. The results were quite good during the first part of the series when the Low was moving eastward but when the sharp shift toward the southwest occurred the computation failed for three consecutive maps. When the change was finally detected, the computed position lagged the actual position by a significant amount and continued thus throughout the remainder of the series. The overall results of this method were certainly no worse than those previously discussed and might well be considered superior in the early part of the series. In utilizing this procedure it often seems advisable to cut down the number of grid units in all directions by a certain percentage so as not to overlap into another pressure or contour system. In the computations made here the full grid was used.

An attempt was made to use the Petterssen equation [4] for calculation of wave speeds; however, it does not lend itself well to reckoning the movement of centers. If one makes the assumption that the center will remain the same distance from the core of the jet stream along the trough (or ridge), then a fair computation on the center may be made. This formula is difficult to apply in several other respects in that it requires, first, a well-defined trough (or ridge) line which lies in a region of plentiful and reliable data not only to give an accurate analysis but also to determine the wind speed in the trough (or ridge). In addition to this it makes no allowance for amplitude of the wave. Of the computations made using this method all projected the system too far ahead and often in a direction at considerable odds to the observed. This latter effect is due in part, at least, to failure of the system to allow for rotation of the trough (or ridge) around either an imaginary or actual center. This limits its use in the calculation of many short-wave movements to very short periods of time. As it was applied to this specific case the choice of values and locations of the trough was so uncertain as to make highly questionable the results obtained. The question arises whether this method should be applied to systems such as this.

Examination was made of the Scherhag Theory [5] that steering of what Scherhag terms "cold air drops" (cold Lows aloft with no closed circulation at the surface) is controlled by the surface and lower-level flow. Scherhag states that the movement will be deflected across the iso-

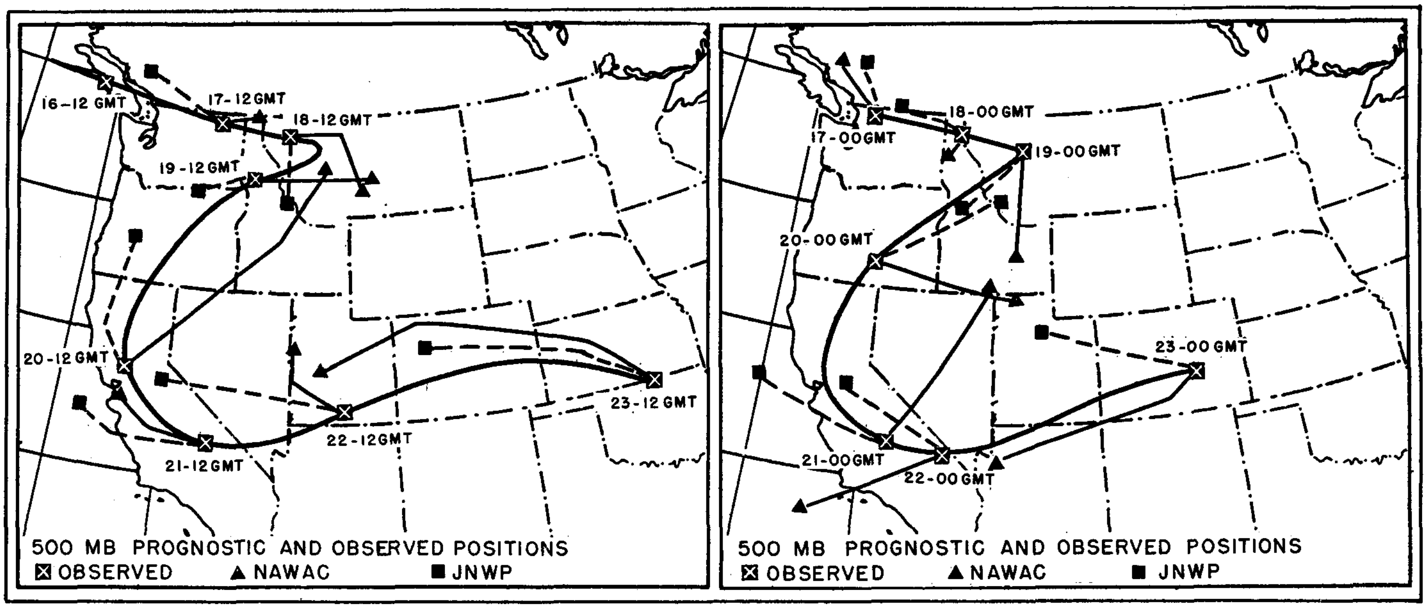


FIGURE 6.—36-hour 500-mb. prognostic positions of low center—NAWAC (triangles) and JNWP (squares)—with connecting lines showing corresponding observed positions. (1200 GMT, October 16–23 left, and 0000 GMT, October 17–23, right.)

bars toward lower pressure and at a speed somewhat less than the gradient wind indicated by the sea level isobars. He does not, however, assign any quantitative values. In applying his theory to this study, 80 percent of the gradient wind speed and a 20° deflection across the isobars were chosen. The system has a very limited application and could be used in only a part of this sequence. The results obtained, however, were the best and about the only calculations that indicated motion of the Low toward the southwest during the early part of the series before and at the time the Low actually started to move in that direction. This, of course, began too soon because some easterly flow was indicated under the Low from its inception. However, one must realize there existed an influence tending to move the Low eastward which had first to be overcome before it could be moved with the current below. The effects of the east-west flow at the surface were very evident in the deceleration pattern from the 16th to the 19th, and in the acceleration afterward. It appears from this very limited application of Scherhag's theory that better results might be obtained by using a deflection angle of approximately 40° across the existing surface isobars or else prognosticating the surface flow pattern at 12-hour intervals and then moving the upper Low with the mean current.

Bjerknes' eccentricity formula [6] gave results as variable as the Low movement itself but not generally in phase with it. Here again proper selection of pattern, orientation of trough line, and accurate wind speeds are all-important. A still further limitation is the latitudinal five-degree radius of curvature found by O'Connor [7] to be the only radius yielding good results. It would appear from experience in this case that the eccentricity formula should be applied only when there is no doubt of a proper fit and reliable data.

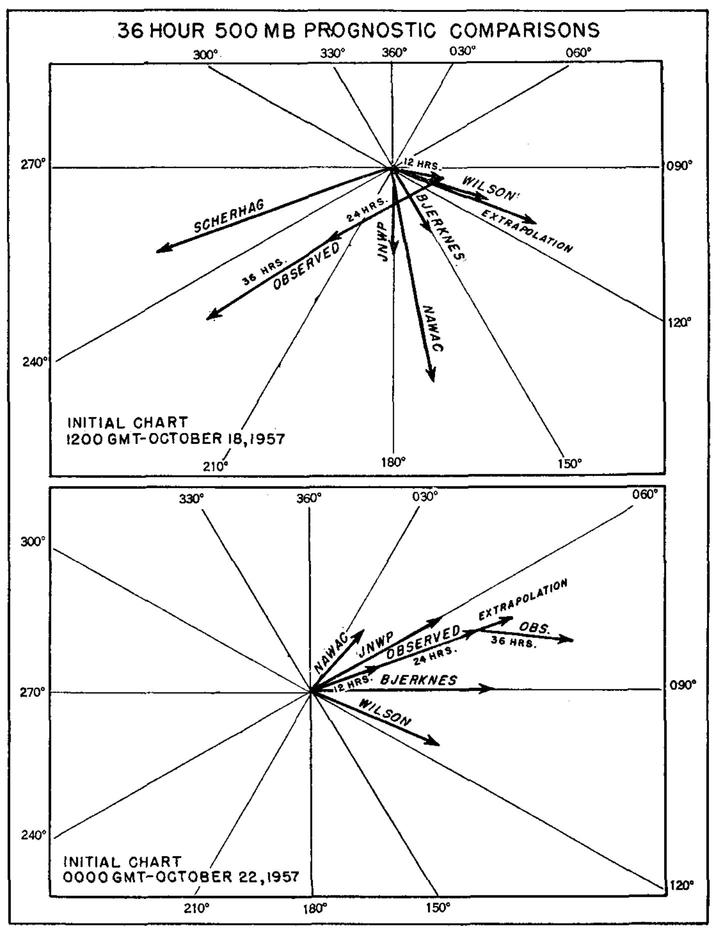


FIGURE 7.—Hodographic form of 36-hour 500-mb. prognostic comparison showing a variety of movement computations with 12-hour vectors of observed movement at two critical periods of the series.

As another approach the Martin anomaly charts [8] were compared with the daily departure from normal maps for the series. There did appear to be some positive relationship between above normal heights over southern Alaska and falling heights later over the western United States; however, the better correlation was found with the summer group. Since October was considered a transition period between the summer and winter averages the forecaster would be hard put to decide which to favor.

For the final experiment a number of constant absolute vorticity trajectories were computed. Here the selection of inflection points throughout the middle part of the series gave angles near the critical 130° value. This in turn indicated the Low would move offshore and cut off considerably too far to the south. It is interesting, on the other hand, that this computation signaled movement toward the south 24 hours ahead, and toward the southwest 12 hours before it began.

5. SUMMARY OF PREDICTION RESULTS

Figure 7 presents two hodographic forms of comparison for some of the techniques discussed in the foregoing paragraphs. These comparisons are made for two of the most critical periods of the sequence, and represent fairly well the relative values of these various procedures as they apply in this specific problem.

It is of considerable interest that most procedures start out by projecting the system in the nearly correct instantaneous direction and that the variations that do exist are so often tending toward the direction toward which the system later turns. One fault clearly pointed up is that so many methods show only a linear projection of movement for whatever the period. This in turn may be very misleading as to where a pressure center has been in the interval, how fast it has moved, and where and how fast it is presently going. The answer here must be then in multiple prognostic periods of short enough range to show all the important variations, which is of course one of the more important advantages of machine prediction.

In any event it seems fairly conclusive that no single one of the procedures examined here was satisfactory for prognosticating more than two or three of the more than a dozen charts of this group. This then just reemphasizes the already well known fact that there is still considerable room for improvement in the realm of weather prognostication.

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